In-situ U-Pb dating and hydrogen analyses of apatite in the basaltic eucrites

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Introduction: Water is one of the most important volatiles that determine the planetary environments (e.g. magmatic activities, climates and habitability). Despite its importance, questions concerning its origin, such as when and from where the water was supplied to the inner solar system have been poorly understood. Eucrites, a group of howardites-eucrites-diogenites meteorites (HEDs), are considered to be samples of the ancient crustal components from the asteroid 4 Vesta [1], which experienced planetary differentiation by ~5 million years after CAI [2]. The water records in the early differentiated bodies such as Vesta will provide us the insight to the source and the timing of water supply to the terrestrial planets. Igneous phosphates in the eucrites (e.g. apatite) may have preserved the magmatic water during the Vesta’s crustal formation, as well as U-Pb chronological information. In this study, we conducted the in-situ U-Pb dating and the hydrogen analyses of apatite in the two basaltic eucrites, Agoult and Camel Donga.
Samples: Agoult is an unbrecciated granulite, which experienced the strong reheating with partial re-melting [3]. The Pb-Pb age of its zircon and plagioclase are 4554 ±2.0 Ma [4] and 4532.4 ±0.8 Ma, respectively [5]. Camel Donga is a monomict breccia with abundant Fe metal (~2wt%), associated with the later reduction of igneous phases [6]. The Pb-Pb age of its zircon is 4531 ±10 Ma [7], younger than those of Agoult and other eucrites. By SEM-EDX observation of the polished sections, we identified several euhedral to subhedral apatite grains (20-100μm) in Agoult and anhedral apatite grains (10-200μm) in Camel Donga.
Analyses: Both U-Pb and hydrogen analyses were conducted using NanoSIMS 50 at AORI, UTokyo. The sample sections were first baked at ~100C in the NanoSIMS air-lock overnight and then kept in the vessel at < 5E-9 torr for 1 week, to remove the adsorbed water. The previously established NanoSIMS analytical methods of U-Pb were applied [8]. For hydrogen analyses, negative secondary ions of H, D, ^{12}C and ^{18}O were collected to calculate water contents and D/H ratios. The background level of hydrogen is ~56 ppm as H_2O.
Results & Discussion: The Agoult apatite has concordant ^{238}U-^{206}Pb and ^{207}Pb-^{206}Pb ages at 4476 ±160 Ma and 4486 ±61 Ma, respectively. The total Pb/U age is 4523 ±13 Ma, significantly younger than Agoult zircon but consistent with the plagioclase and Camel Donga zircon. It is suggested that these younger minerals may have recorded the same reheating event at ~4523 Ma or the slow cooling in the Vesta’s crust. The Camel Donga apatite has U-Pb and Pb-Pb ages at 4478 ±86 Ma and 4474 ±83 Ma, indicating it may have the same thermal records to that of Agoult apatite. The H_2O contents of them are < 100 ppm for Agoult and < 1,000 ppm for Camel Donga. Though their D/H ratios cannot be determined due to the low water contents, such dry apatite is consistent with the reductive conditions, previously estimated from the Agoult zircon [4] and Camel Donga metal [6]. Our results suggest that Vesta’s crust, at least locally, was depleted in water at ~4523 Ma.
Refs: [1] McSween et al. (2013) MaPS 48, 2090-2104. [2] Srinivasan et al. (1999) Sci. 284, 1348-1350. [3] Yamaguchi et al. (2009) GCA 73, 7162-7182. [4] Iizuka et al. (2015) EPSL 409, 182-192. [5] Iizuka et al. (2013) LPSC abst. 1907. [6] Palme et al. (1988) Meteoritics 23, 49-57. [7] Zhou et al. (2013) GCA 110, 152-175. [8] Koike et al. (2014) GJ 48, 423-431.

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